NASA Technical Memorandum 102013

Gas Density Effect on Dropsize of Simulated Fuel Sprays

(NASA-TM-102013) GAS DENSITY EFFECT ON DROPSIZE OF SIMULATED FUEL SPRAYS (NASA-Lewis Research Center) 14 p CSCL 20D

N89-22053

Unclas
G3/34 0204357

Robert D. Ingebo
Lewis Research Center
Cleveland, Ohio

Prepared for the
25th Joint Propulsion Conference
cosponsored by the AIAA, ASME, SAE, and ASEE
Monterey, California, July 10–12, 1989

NASA

GAS DENSITY EFFECT ON DROPSIZE OF SIMULATED FUEL SPRAYS

Robert D. Ingebo
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-4725

Abstract

Two-phase flow in pneumatic two-fluid fuel nozzles was experimentally investigated to determine the effect of atomizing-gas density and gas mass-flux on liquid-jet breakup in sonic-velocity gas-flow. Dropsize data were obtained for the following atomizing-gases: nitrogen, argon, carbon dioxide and helium. They were selected to cover a gas molecular-weight range of 4 to 44. Atomizing-gas mass-flux ranged from 6 to 50 g/cm^2-sec and four differently sized two-fluid fuel nozzles were used having orifice diameters that varied from 0.32 to 0.56 cm.

The ratio of liquid-jet diameter to SMD, D_o/D_{32}, was correlated with aerodynamic and liquid-surface forces based on the product of the Weber and Reynolds number, We Re, and gas-to-liquid density ratio, ρ_g/ρ_l. To correlate spray dropsize with breakup forces produced by using different atomizing-gases, a new molecular-scale dimensionless group was derived, $\rho_l V_m^3/g\mu_g$, and used to obtain the following expression:

$$D_o/D_{32} = 4.33\times10^{-11}\left(\text{We Re}\ \rho_g/\rho_l\right)^{0.44}\left(\rho_l V_m^3/g\mu_g\right)^{0.75}$$

where $\text{We Re} = \rho_g^2 D_o^2 V_c^3/\sigma\mu_l$, μ_l is liquid viscosity, σ is surface tension, V_c is acoustic gas velocity, V_m is RMS velocity of gas molecules, g is acceleration of gas molecules due to gravity, and μ_g is gas viscosity.

From this expression for liquid-jet breakup in two-fluid atomizers, it is evident that $D_{32}^{-1} \sim \left(\rho_g V_c\right)^{1.33}$. This expression agrees well with atomization theory for liquid-jet breakup in high-velocity gasflow, i.e., in the regime of aerodynamic stripping. Also, it was found that at the same gas mass-flux, $\rho_g V_c$, helium was considerably more effective than nitrogen in producing small-droplet sprays with SMD's in the order of 5 μm.

Nomenclature

b	dropsize parameter in Nukiyama-Tanasawa expression, cm
c	dropsize parameter in Rosin-Rammler expression, cm
D_c	characteristic drop diameter measured for entire spray, cm
D_i	diameter of ith drop, cm
$D_{v.5}$	volume median drop diameter, cm
D_{31}	volume-linear mean drop diameter, $\left[\sum_i nD_i^3/\sum_i nD_i\right]^{0.5}$
D_{32}	Sauter mean drop diameter, $\sum_i nD_i^3/\sum_i nD_i^2$, cm
k	correlation coefficient for Eq. (1)
k'	correlation coefficient for Eq. (3)
N_n	exponent for Nukiyama-Tanasawa dropsize distribution expression
N_r	exponent for Rosin-Rammler dropsize distribution expression
n	number of droplets
R	gas constant, 8.31×10^7 ergs
Re	Reynolds number, $D_o\rho_g V_c/\mu$
V	fluid velocity, cm/sec
v	volume fraction of droplets with diameters less than or equal to x
W	weight flow of fluid, g/sec
We	Weber number, $D_o\rho_g V_c^2/\sigma$
x	droplet diameter in dropsize distribution expression, cm
μ	absolute viscosity, g/cm sec
ρ	fluid density, g/cm^3
σ	surface tension of liquid relative to air, dynes/cm

Subscripts:

c	acoustic
g	gas
l	liquid
m	molecular
o	orifice
w	water

Introduction

Liquid-fueled gas turbine and rocket combustor performance can be markedly improved with two-fluid fuel nozzles capable of producing large numbers of small fuel droplets, i.e., fuel sprays that have a large liquid surface-area to volume ratio. This improvement in combustor performance is due to the fact that large surface-area sprays yield high vaporization and burning rates. The very small droplets produced by this type of atomizer vaporize

fast enough so that it may also be used to form premixed-prevaporized fuel-air mixtures suitable for application in catalytic combustors.

As reported in Ref. 1, an investigation was previously conducted using four differently sized two-fluid nozzles. It was found that reciprocal Sauter mean diameter, D_{32}^{-1}, could be correlated with the product of the Weber number, Reynolds number, and gas-to-liquid density ratio raised to the 0.44 power as follows: $D_{32}^{-1} \sim \left(We\ Re\ \rho_g/\rho_l\right)^{0.44}$. This relationship shows that $D_{32} \sim V_c^{-1.33}$ where V_c is acoustic gas velocity. The exponent agrees with that predicted by atomization theory for liquid-jet breakup in high velocity gasflow.

Numerous investigators have studied the effect of fluid properties on liquid-jet atomization. Some of their results are given in Refs. 2 to 4. Of all the fluid properties that affect atomization, it was found in Ref. 1, that acoustic mass-flux, $\rho_g V_c$, had the greatest effect on the fineness of atomization obtained with two-fluid nozzles. However at present, the independent effect of gas density, ρ_g, on spray dropsize has not been very well established in the literature as indicated in Refs. 5 and 6. Therefore, in the present study, the effect of gas density on spray dropsize was investigated. To accomplish this, acoustic gas-velocity was held constant while gas density was varied. In addition, a wide range of acoustic gas-velocities was investigated by using four different atomizing gases having molecular weights ranging from 4 to 44. The gases used were helium, nitrogen, argon and carbon dioxide.

In the present study, two-phase flow in fuel nozzles was experimentally investigated to determine the effect of acoustic gas-velocity and mass-flux on characteristic spray dropsizes produced by liquid-jet breakup in high velocity gasflow. Characteristic dropsizes were measured with a scattered-light scanner developed at the NASA Lewis Research Center.[7] The sprays were sampled at a distance of 2.2 cm downstream of the fuel-nozzle orifice, to minimize the loss of small droplets due to vaporization and dispersion. The sprays were injected into a low velocity, 5 m/sec, stream to aid in transporting very small droplets through the laser beam. Small-droplet sprays with Sauter mean diameters varying from 3 to 30 μm were produced by the atomization of small-diameter liquid jets in the regime of aerodynamic-stripping, i.e., high-velocity gasflow. Liquid and gas pressures were varied from 0.2 to 1.0 MPa.

Apparatus and Procedure

A two-fluid atomizer was mounted horizontally in the open duct as shown in Fig. 1. Air supplied at ambient temperature, 293 K, passed through the 24 cm inside diameter test section before being exhausted to the atmosphere. The test section was 1 m in length and airflow rate in the test section was measured with a 5.08 cm diameter orifice. To aid in transporting small droplets through the laser beam, an airstream velocity of 5 m/sec was maintained in the test section. Figure 2 shows a schematic drawing of the spray and instrumentation.

Four pneumatic two-fluid atomizers were fabricated according to the diagram illustrated in Fig. 3 with orifice diameters ranging from 0.32 to 0.56 cm. The atomizer was operated over pressure ranges of 0.2 to 1.0 MPa for both water and the atomizing gas. Sprays were injected downstream into the airflow just upstream of the duct exit. The sprays were sampled at a distance of 2.2 cm downstream of the atomizer.

Water at a temperature of 298 K, measured with an I.C. thermocouple, was axially injected into the airstream by gradually opening a control valve until the desired flow rate of 3.15 g/sec was obtained as indicated by a turbine flowmeter. The atomizing gas was then turned on and weight flowrate was measured with a 0.51 cm diameter sharp-edge orifice. After the air, atomizing gas and water flowrates were set, the Sauter mean drop diameter was measured with the scattered-light scanner to characterize each spray. Exponents for the Rosin-Rammler and Nukiyama-Tanasawa dropsize distribution expressions were also determined using the scattered-light scanner.

The optical system of the scattered-light scanner shown in Fig. 2 consists of a laser beam expander with a spatial filter, rotating scanning slit, and a detector. Using a 4.4 by 1.9 cm laser beam, the instrument measures scattered light as a function of scattering angle by repeatedly sweeping a variable-length slit in the focal plane of the collecting lens. The data obtained is scattered-light energy as a function of the scattering angle relative to the laser beam axis. This method of particle size measurement is similar to that given in Ref. 8.

In Ref. 9, it was found that measurements of points on a plot of scattered-light energy normalized to the maximum energy and plotted against scattering angle can be used to determine the Sauter mean diameter, the volume median, the volume linear and the 75-percent volume diameters as illustrated in Fig. 4. The dispersion of the size distribution is also determined from the points on the plot shown in Fig. 4. Also, it should be noted that this method of determining characteristic drop diameters and dispersion of dropsizes can be used independent of the particle size distribution function as discussed in Ref. 9. For a typical measurement, the scan is repeated 60 times per second to average out any temporal variations in the energy curve.

Spray pattern effects were minimized by measuring characteristic drop diameters using the entire spray. Reproducibility using this technique was within ±5 percent. Calibration was accomplished with five sets of monosized polystyrene spheres having diameters of 8, 12, 25, 50, and 100 μm. Since the present sprays were sampled very close to the atomizer orifice, they contained a relatively high number-density of very small drops. As a result, the light-scattering measurements required correction for multiple scattering as described in Ref. 10.

Drop size measurements were also corrected to include Mie scattering theory when very small droplet diameters, i.e., <10 μm, were measured.

Experimental Results

Four atomizing gases, i.e., nitrogen, argon, carbon dioxide and helium were used in two-fluid fuel nozzles to study the effect of atomizing-gas density on spray dropsize. To demonstrate this

effect, several dimensionless groups were investigated.

Effect of Atomizing-Gas Mass-Flux on Spray Dropsize

The reciprocal SMD, D_{32}^{-1} was plotted against atomizing-gas flowrate per unit area as shown in Fig. 5. From this plot, the following relationship is obtained for the four atomizing-gases, helium, nitrogen, argon and carbon dioxide:

$$D_{32}^{-1} = k\left(W_g/A_o\right)^{1.33} \tag{1}$$

where k is a correlation coefficient that is a function of the gas used to atomize water jets. Equation (1) can be rewritten in terms of gas mass-flux as follows:

$$D_{32}^{-1} = k\left(\rho_g V_g\right)^{1.33} \tag{2}$$

Values of the correlation coefficient, k, for each atomizing gas are given in Table 1.

The four atomizing gases show good agreement with atomization theory,[11] which predicts reciprocal SMD to be directly proportional to gas velocity raised to the 1.33 power. This exponent also agrees well with the results previously reported in Ref. 1 and the value of 11.5 obtained for the coefficient k is in good agreement with that reported in Ref. 7 for two-fluid atomizers using nitrogen gas.

A comparison of k values clearly shows the marked improvement that is obtained in fineness of atomization when a low-density gas such as helium is used as the atomizing gas for two-fluid fuel nozzles operating at acoustic gas velocities. The attainment of a large liquid-surface area per unit volume of liquid, i.e., large values of reciprocal SMD, D_{32}^{-1}, with the use of helium is attributed to the low molecular weight and therefore high acoustic-velocity of helium. On the other hand, the higher molecular weights and lower acoustic velocities of argon and carbon dioxide make them much less efficient as atomizing-gases for two-fluid fuel nozzles operating at acoustic gas velocities.

Correlation of Normalized Reciprocal SMD with Dimensionless Groups

In the study of liquid-jet breakup in high-velocity nitrogen gasflow that is reported in Ref. 1, it was found that the reciprocal of the normalized SMD, $(D_{32}/D_o)^{-1}$, could be directly correlated with the product of the Weber and Reynolds numbers, We Re, multiplied by the gas-to-liquid density ratio, ρ_g/ρ_l, as follows:

$$D_o/D_{32} = k'(\text{We Re}\ \rho_g/\rho_l)^{0.44} \tag{3}$$

where $\text{We Re} = D_o^2\rho_g^2V_c^3/\mu_g\sigma$ and V_c is the acoustic velocity of the gas. Atomization data obtained for the four atomizing gases are shown in Fig. 6. From the slope of the plots, a correlation coefficient k' was determined for each atomizing-gas and values of k' are recorded in Table 1.

Effect of Atomizing-Gas Properties on Liquid-Jet Breakup

The primary objective of this investigation was to study liquid-jet breakup in two-fluid atomizers by using four different atomizing-gases and correlate reciprocal Sauter mean diameter, D_{32}^{-1}, with atomizing-gas properties. As shown in Fig. 6, the product of the Weber and Reynolds numbers and the density ratio do not give a single correlation expression. In order to accomplish the objective of this study, the normalized reciprocal Sauter mean diameter, D_o/D_{32}, produced by liquid-jet breakup with two-fluid atomizers is also assumed to be a function of the RMS velocity of the gas molecules, V_m, the acceleration of gas molecules due to gravity, g, atomizing-gas viscosity, μ_g, and liquid density, ρ_l. Using dimensional analysis, the following expressions are obtained:

$$D_o/D_{32} = f(V_m, \mu_g, \rho_l, g) \tag{4}$$

where $V_m = \sqrt{3RT_g}/M_g$. [12] By rewriting Eq. (4), there results:

$$D_o/D_{32} = f(\rho_l)^a(V_m)^b(g)^c(\mu_g)^d \tag{5}$$

The preceding equation is then expressed in terms of the mass-length-time system (where T is time; M, mass; and L, length) to give:

$$\frac{D_o}{D_{32}} = f\left(\frac{M}{L^3}\right)^a\left(\frac{L}{T}\right)^b\left(\frac{L}{T^2}\right)^c\left(\frac{M}{LT}\right)^d \tag{6}$$

so that for:

$$M,\ 0 = a + d$$

$$T,\ 0 = -b - 2c - d$$

$$L,\ 0 = -3a + b + c - d$$

which may be written as:

$$a = -d$$

$$b = -2c - d = -3d$$

$$c = 3a - b + d$$

Substitution of these values into Eq. (5) gives:

$$D_o/D_{32} = f\left(\rho_l V_m^3/g\mu_g\right)^{-d} \tag{7}$$

To obtain a general correlating expression for the four atomizing-gases, the correlation coefficient k' is plotted against $\rho_l V_m^3/g\mu_g$. From the slope of this plot shown in Fig. 7, the following relationship is obtained:

$$k' = \left(\rho_l V_m^3/g\mu_g\right)^{0.75} \tag{8}$$

where the exponent -d, derived from dimensionless analysis is equal to 0.75. Since this exponent is fairly large, the variables μ_g, ρ_l, V_m, and g have a very important effect on the liquid-jet breakup process. Microgravity studies are needed in which g is varied to determine if the exponent 0.75 is correct for g.

To obtain a single correlating coefficient for the atomizing-gases, values of D_o/D_{32} are plotted against the product of the dimensionless groups given in Eqs. (3) and (8), as shown in Fig. 8. Thus the following expression is obtained for the four atomizing gases:

$$D_o/D_{32} = 4.33\times10^{-11}\left(We\ Re\ \rho_g/\rho_l\right)^{0.44}\left(\rho_l V_m^3/g\mu_g\right)^{0.75} \qquad (9)$$

Since $We\ Re(\rho_g/\rho_l) = D_o^2\left(\rho_g V_c\right)^3/\mu_l\rho_l\sigma$, it is evident that the reciprocal Sauter mean diameter is proportional to $V_m^{2.1}$, $\rho_l^{0.31}$, $\mu_g^{-0.75}$ and gas molecular weight raised to the -0.46 power. For the liquid properties, D_{32}^{-1} is proportional to $\mu_l^{-0.44}$, $\sigma^{-0.44}$ and $\rho_l^{0.31}$. These exponents give fairly good agreement with those predicted by atomization theory, as shown in Table 2. Therefore Eq. (9), although it was derived for water-jet breakup, should give fairly good results in predicting fuel-jet breakup in Mach 1 gasflow with two-fluid nozzles.

Correlation of Exponents for Dropsize Distribution Expressions

The scattered-light scanner gave data for the exponent N_r, which appears in the Rosin-Rammler expression as follows:[13]

$$\frac{dv}{dx} = \frac{N_r x^{N_r-1}}{cN_r}\, e^{-(x/c)^{N_r}} \qquad (10)$$

Data were also obtained for the exponent N_n, which appears in the Nukiyama-Tanasawa expression as follows:[13]

$$\frac{dv}{dx} = \frac{b^{6/N_n}}{\Gamma(6/N_n)}\, x^{5} e^{-bx^{N_n}} \qquad (11)$$

From a plot of the data obtained with the four atomizers, as shown in Fig. 9, the following relation was determined:

$$N_r = 2.8N_n^{0.45} \qquad (12)$$

which is the same as that derived in Ref. 1. Thus it was found that the relation between exponents N_n and N_r was not appreciably affected when the atomizing-gas molecular weight was varied from 4 to 44.

Summary of Results

From the correlating expressions derived in this study, it is evident that:

1. The effect of atomizing-gas density, ρ_g, on spray dropsize is the same as that of acoustic velocity, V_c, i.e., $D_{32}^{-1} \sim (\rho_g V_c)^{1.33}$.

2. RMS gas molecular-velocity, V_m, and acoustic mass-flux, $\rho_g V_c$, have the greatest effect of all gas- and liquid-phase properties on the process of liquid-jet breakup in high-velocity gasflow.

3. The reciprocal SMD, D_{32}^{-1}, produced with two-fluid atomizers was considerably greater for helium in comparison with nitrogen, at the same gas mass-flux. The superior performance of helium gas as compared with that obtained with nitrogen, is attributed to the relatively high acoustic and RMS molecular velocities of helium.

Appendix - Characteristic Dropsize of Liquid Fuel-Sprays Simulated by Water-Jet Breakup in High-Velocity Gasflow

Values of liquid properties given in Table 3 were used in Eq. (9) to calculate reciprocal Sauter mean diameters for JP-5 and n-Octane fuel-sprays. These are plotted against gas mass-flux in Fig. 10. Two sets of plots are presented. The elevation of the upper set over the lower one shows the effect on spray surface-area that is obtained, according to Eq. (9), when helium gas is used in two-fluid atomizers instead of nitrogen gas. From these plots, values of k were calculated and are recorded in Table 3.

References

1. Ingebo, R.D., "Fluid Spray Simulation With Two-Fluid Nozzles," AIAA Paper 89-0053, Jan. 1989. (NASA TM-101367)

2. Weiss, M.A., and Worsham, C.H., "Atomization in High Velocity Airstreams," American Rocket Society Journal. Vol. 29, No. 4, Apr. 1959, pp. 252-259.

3. Wolfe, H.E., and Andersen, W.H., "Aerodynamic Breakup of Liquid Drops," Proceedings of the 5th International Shock Tube Symposium, Z.I. Slawsky, J.F. Moulton, Jr., and W.S. Filler, Eds., Naval Ordnance Lab., White Oak, MD, 1965, pp. 1145-1169. (Avail. NTIS. AD-638011.)

4. Kim, K.Y., and Marshall, W.R., Jr., "Drop-Size Distributions from Pneumatic Atomizers," AIChE Journal, Vol. 17, No. 3, May 1971, pp. 575-584.

5. Nukiyama, S., and Tanasawa, Y., "Experiment on Atomization of Liquid, "Transactions of the Society of Mechanical Engineers, Japan, Vol. 5, No. 18, Feb. 1939, pp. 63-75.

6. Lorenzetto, G.E., and Lefebvre, A.H., "Measurements of Drop-Size on a Plain-Jet Airblast Atomizer," AIAA Journal. Vol. 15, No. 7, July 1977, pp. 1006-1010.

7. Ingebo, R.D., and Buchele, D.R., "Small-Droplet Spray Measurements With a Scattered-Light Scanner," NASA TM-100973, Nov. 1988.

8. Swithenbank, J., Beer, J.M., Taylor, D.S., Abbot, D., and McCreath, G.C., "A Laser Diagnostic Technique for the Measurement of Droplet and Particle Size Distribution," AIAA Paper 76-69, Jan. 1976.

ORIGINAL PAGE IS
OF POOR QUALITY

9. Buchele, D.R., "Particle Sizing By Weighted Measurements of Scattered Light," NASA TM-100968, 1988.

10. Felton, P.G., Hamidi, A.A., and Aigal, A.K., "Measurement of Drop-Size Distribution in Dense Sprays by Laser Diffraction," 3rd International Conference on Liquid Atomization and Spray Systems, ICLASS - 85, Vol. 2, P. Eisenklam and A. Yule, Eds., Institute of Energy, London, 1985, pp. IVA/4/.-IVA/4/11.

11. Adelberg, M., "Mean Drop-Size Resulting from the Injection of a Liquid Jet Into a High-Speed Gas Stream," AIAA Journal, Vol. 6, No. 6, June 1968, pp. 1143-1147.

12. Glasstone, S., Textbook of Physical Chemistry, D. Van Nostrand Co. Inc., New York, 2nd Edition, 1946, p. 253.

13. Mugele, R.A., and Evans, H.D., "Droplet Size Distribution in Sprays," Industrial and Engineering Chemistry, Vol. 43, No. 6, June 1951, pp. 1317-1324.

TABLE 1. - CORRELATION COEFFICIENTS FOR ATOMIZING GASES

Atomizing-gas	Correlation coefficients	
	k, Eq. (1)	k', Eq. (3)
He	86.5	53
N_2	11.5	7.5
Ar	6.3	4.0
CO_2	6.3	4.0

TABLE 2. - EFFECT OF PHYSICAL PROPERTIES ON RECIPROCAL SMD, AT MACH 1 GASFLOW

Source	Relationship
Gas-phase properties	
Present study	$D_{32}^{-1} \sim V_c^{1.33} \cdot \rho_g^{1.33} \cdot \mu_g^{-0.75} \cdot M_g^{-0.46} \cdot V_m^{2.25}$
Theory	$D_{32}^{-1} \sim V_g^{1.33} \cdot \rho_g^{0.67} \cdot \mu_g^{0} \cdot M_g^{0} \cdot V_m^{0}$
Liquid-jet properties	
Present study	$D_{32}^{-1} \sim \rho_l^{0.31} \cdot \mu_l^{-0.44} \cdot \sigma^{-0.44}$
Theory	$D_{32}^{-1} \sim \rho_l^{0.33} \cdot \mu_l^{0.67} \cdot \sigma^{-0.33}$
Other terms	
Present study	$D_{32}^{-1} \sim D_o^{-0.2} \cdot g^{-0.75}$
Theory	$D_{32}^{-1} \sim D_o^{0} \cdot g^{0}$

TABLE 3. - LIQUID-JET PHYSICAL PROPERTIES AT 20 °C AND VALUES OF k FOR EQ. (1)

Liquid	Physical properties			Values of k for atomizing-gases	
	$\mu_l \times 10^2$, poises	σ, dynes/cm	ρ_l, g/cc	N_2	He
Water	10.10	72.8	1.00	[a]11.5	[a]86.5
JP-5	15.8	28.5	.68	[b]12.7	[b]95.3
n-Octane	5.42	21.8	.82	[b]24.2	[b]181.7

[a]Experimental.
[b]Calculated.

ORIGINAL PAGE IS
OF POOR QUALITY

FIGURE 1. - APPARATUS AND AUXILLIARY EQUIPMENT.

ORIGINAL PAGE IS
OF POOR QUALITY

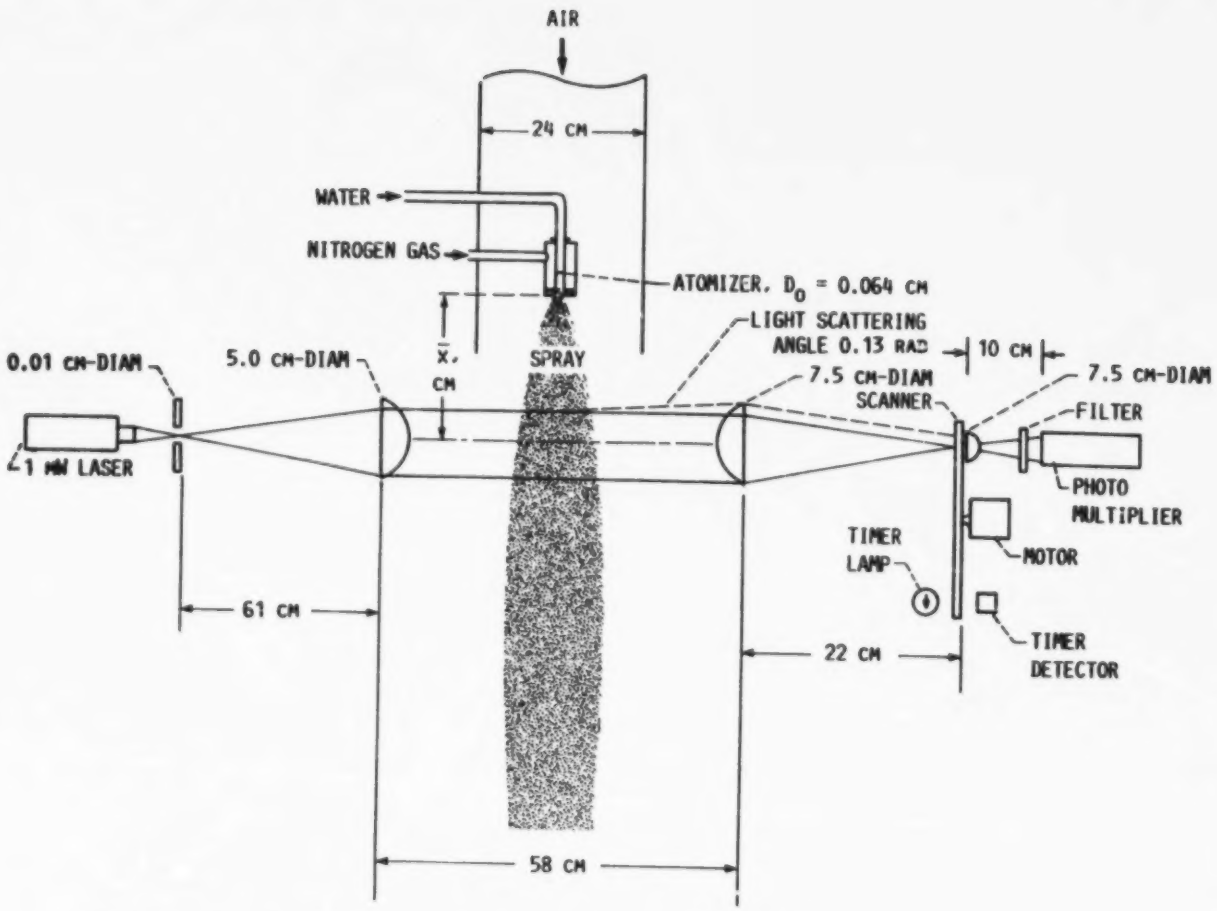

FIGURE 2. - ATMOSPHERIC PRESSURE TEST SECTION AND OPTICAL PATH OF SCATTERED-LIGHT SCANNER.

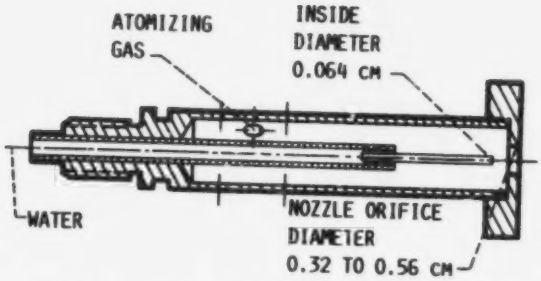

FIGURE 3. - DIAGRAM OF PNEUMATIC TWO-FLUID ATOMIZER.

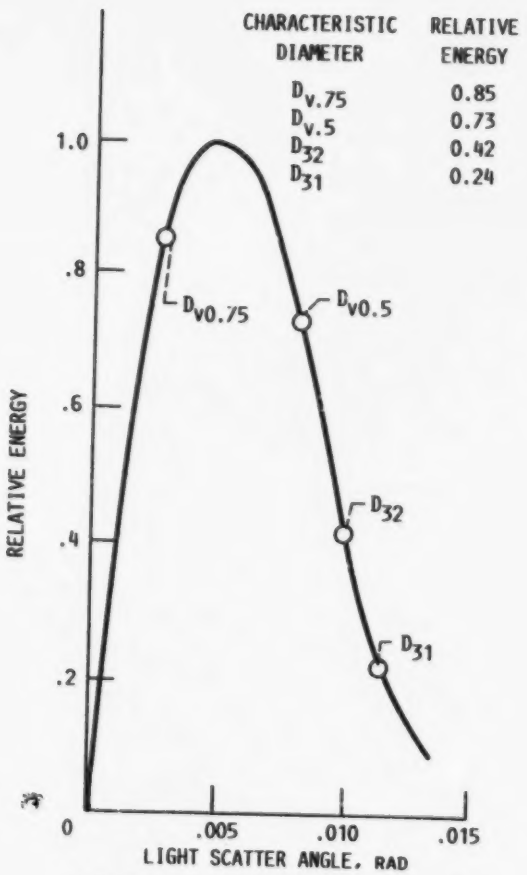

FIGURE 4. - TYPICAL SCATTERED-LIGHT ENERGY CURVE WITH FOUR CHARACTERISTIC DIAMETERS.

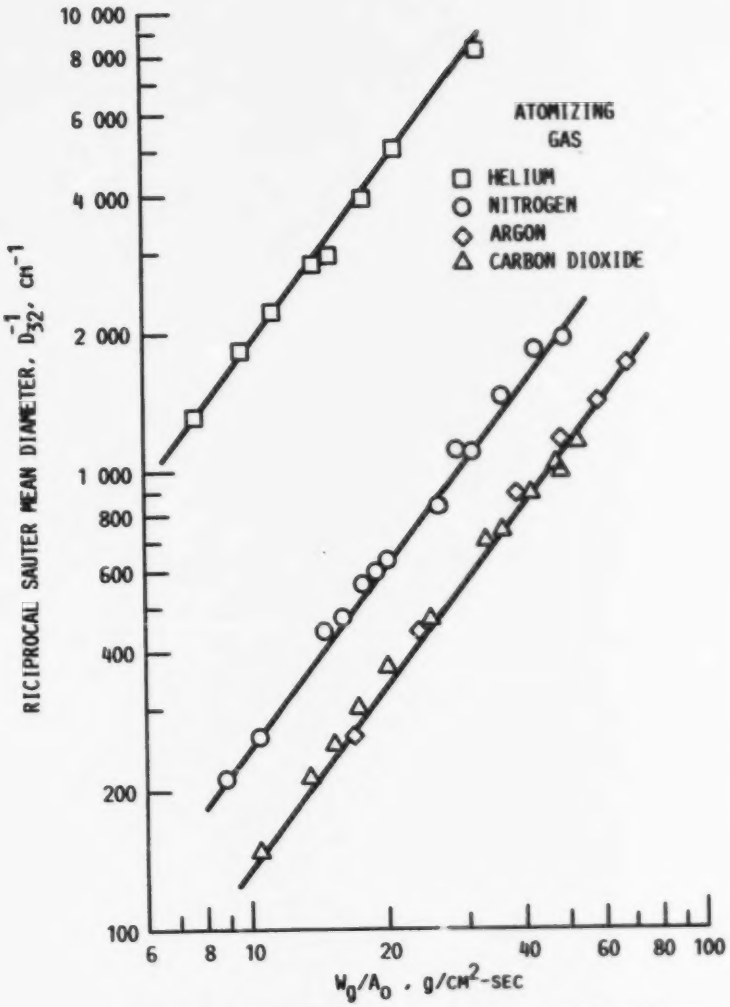

FIGURE 5. - VARIATION OF RECIPROCAL SAUTER MEAN DIAMETER WITH GAS FLOWRATE PER UNIT AREA, W_g/A_o, AT A LIQUID FLOWRATE OF 3.15 g/sec.

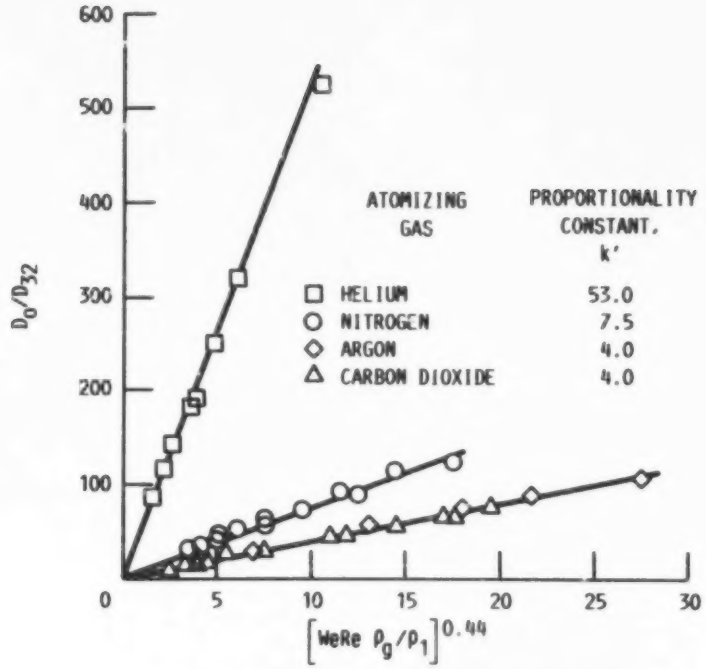

FIGURE 6. - CORRELATION OF SAUTER MEAN DIAMTER, D_{32}, WITH DIMENSIONLESS GROUP WeRe AND FLUID DENSITY RATIO.

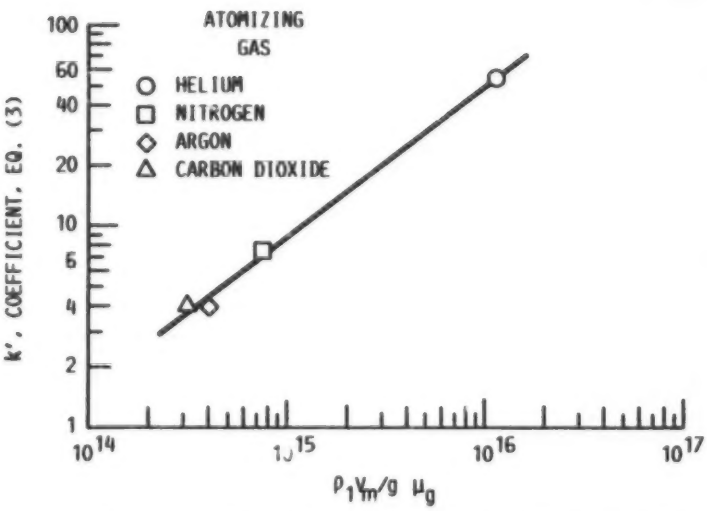

FIGURE 7. - CORRELATION OF PROPORTIONALITY COEFFICIENT k' WITH DIMENSIONLESS GROUP $\rho_i V_m/g\ \mu_g$.

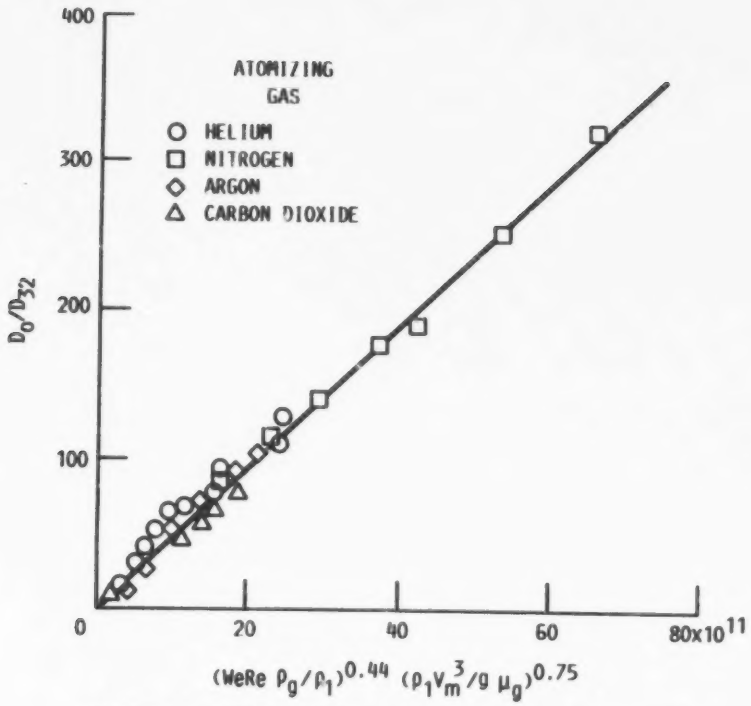

FIGURE 8. - CORRELATION OF NORMALIZED RECIPROCAL SAUTER MEAN DIAMETER WITH DIMENSIONLESS GROUPS.

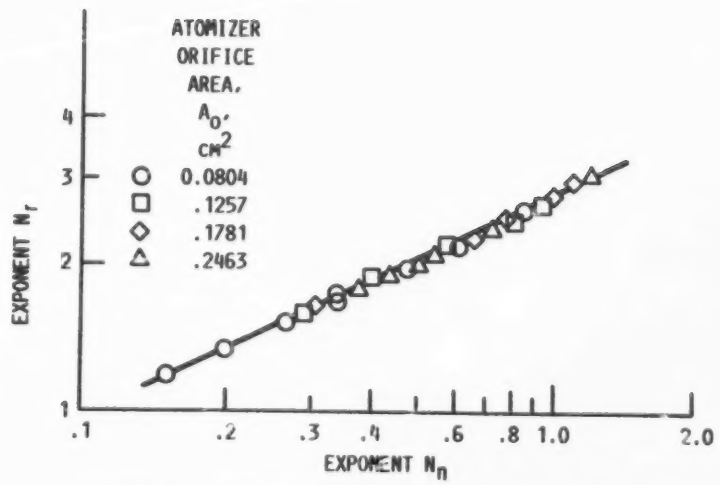

FIGURE 9. - CORRELATION OF ROSIN-RAMMLER AND NUKIYAMA TANASAWA EXPONENTS N_r AND N_n, RESPECTIVELY.

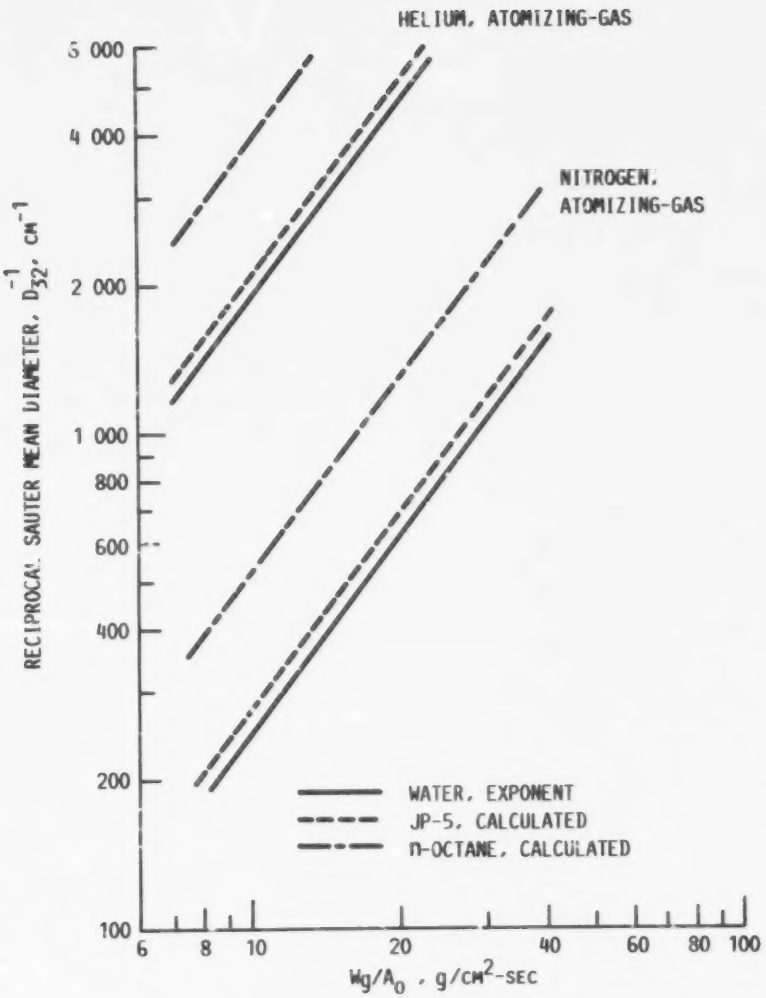

FIGURE 10. - COMPARISON OF RECIPROCAL SMD'S FOR WATER WITH FUEL-SPRAY CALCULATED VALUES

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-102013		

4. Title and Subtitle	5. Report Date
Gas Density Effect on Dropsize of Simulated Fuel Sprays	
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Robert D. Ingebo	E-4725
	10. Work Unit No. 505-62-21

9. Performing Organization Name and Address	11. Contract or Grant No.
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	
	13. Type of Report and Period Covered: Technical Memorandum

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, D.C. 20546-0001	

15. Supplementary Notes

Prepared for the 25th Joint Propulsion Conference cosponsored by the AIAA, ASME, SAE, and ASEE, Monterey, California, July 10-12, 1989.

16. Abstract

Two-phase flow in pneumatic two-fluid fuel nozzles was experimentally investigated to determine the effect of atomizing-gas density and gas mass-flux on liquid-jet breakup in sonic-velocity gasflow. Dropsize data were obtained for the following atomizing-gases: nitrogen, argon, carbon dioxide and helium. They were selected to cover a gas molecular-weight range of 4 to 44. Atomizing-gas max-flux ranged from 6 to 30 g/cm^2-sec and four differently sized two-fluid fuel nozzles were used having orifice diameters that varied from 0.32 to 0.56 cm. The ratio of liquid-jet diameter to SMD, D_o/D_{32}, was correlated with aerodynamic and liquid-surface forces based on the product of the Weber and Reynolds number, WeRe, and gas-to-liquid density ratio, ρ_g/ρ_l. To correlate spray dropsize with breakup forces produced by using different atomizing-gases, a new molecular-scale dimensionless group was derived, $\rho_l V_m^3/g\mu_g$, and used to obtain the following expression:

$$D_o/D_{32} = 4.16\times10^{-11}\,(\mathrm{WeRe}\,\rho_g/\rho_l)^{0.44}(\rho_l V_m^3/g\mu_g)^{0.75}$$

where $\mathrm{WeRe} = \rho_g^2 D_o^2 V_c^3/\sigma\mu_l$, μ_l is liquid viscosity, σ is surface tension, V_c is acoustic gas velocity, V_m is RMS velocity of gas molecules, g is acceleration of gas molecules due to gravity, and μ_g is gas viscosity. From this expression for liquid-jet breakup in two-fluid atomizers, it is evident that $D_{32}^{-1} \sim (\rho_g V_c)^{1.33}$. This expression agrees well with atomization theory for liquid-jet breakup in high-velocity gasflow, i.e., in the regime of aerodynamic stripping. Also, it was found that at the same gas mass-flux, $\rho_g V_c$, helium was considerably more effective that nitrogen in producing small-droplet sprays with SMD's in the order of 5 μm.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Liquid fuel sprays; Atomization; Liquid jet; Fuel nozzles; Mean dropsize; Multi-phase flow	Unclassified - Unlimited Subject Category 34

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	14	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161